

DEVELOPING SPLIT-FLOW™ STORMWATER SYSTEMS

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Abstract

There are significant problems with urban stormwater management practices using current detention, infiltration and bioretention methods. The main problem with current detention methods is that they do not meet current environmental protection goals because they fail to adequately address stormwater volume and quality. The main problem with current infiltration and bioretention methods is that they do not meet flood control goals because they fail to adequately address stormwater peak flow rates when rainfall events occur in which the peak flow rate does not correlate with the specific design storm. What is needed is a site-based urban stormwater management strategy that will meet both our environmental and flood control goals. This paper introduces a newly developed stormwater management strategy that provides a practical, comprehensive and integrated approach to preserving predevelopment stormwater flow rates, quality, volumes, frequency, and duration. This new strategy is based on site-based systems that treat non-point pollution and split runoff into relative portions based on existing hydrological conditions.

Introduction

In the past, different stormwater management systems have been designed to reduce downstream flooding, reduce non-point source pollution, recharge groundwater, and prevent stream degradation. The split-flow strategy is one system designed to do all these things by preserving the predevelopment site hydrology. The result is a management strategy that separates out and retains or infiltrates precisely the runoff volume created by development while the natural runoff that existed before development is cleaned and discharged downstream. As flash flows are maintained at predevelopment levels and first flush is captured on site, the reduction in downstream degradation should be quite substantial. A complete explanation of the development, design and application of the split-flow stormwater management strategy can be found in *Split-Flow Method: Introduction of a New Stormwater Strategy*, in *Stormwater*, July/Aug., Echols, S. (2002) or online at http://www.forester.net/sw_0207_split.html.

This paper will summarize:

1. What are distributed split-flow systems?
2. What are the benefits to be gained through their application?
3. When can distributed split-flow systems be best utilized?
4. What are the hydrological calculations needed to design these systems?
5. How can these systems be used to meet current stormwater regulations?
6. What are the best methods for integrating these systems into site design?
7. How can these systems help guide evolving stormwater policy?

What are distributed split-flow systems?

The basic premise of split-flow stormwater systems is that rainfall can be divided into three portions specific to any given design storm based on existing conditions for evapotranspiration, infiltration and natural runoff volumes and that these portions can be filtered, distributed and redirected respectively into bioretention, recharge and downstream discharge. The traditional objective of stormwater management systems has been to control the peak flow rate for specific design storms. However, the primary objective of split-flow systems is preserving the predevelopment hydrological conditions by retaining and or infiltrating the total

volume difference created by development and thereby controlling peak flow rates for all design storms. The first two objectives are to lengthen the time of concentration and control the first flush by emulating the reduction in runoff adsorbed in the predevelopment initial abstraction. This reduction in runoff is most easily emulated using existing bioretention techniques sized to capture the first flush. The basic methods of designing bioretention systems as a water quality practice using plants and soils to remove stormwater pollutants are outlined in the Prince George's County Government published the *Design Manual for Use of Bioretention in Stormwater Management* prepared by Engineering Technologies Associates, Inc., and Biohabitats, Inc., and subsequent publication explaining Low Impact Development methods including the *Low-Impact Development Manual* (2000) developed by Prince Georges County, Maryland Department of Environmental Resources under the direction of Larry Coffman. In Split-Flow systems, runoff is first directed to a bioretention facility where the designated first flush volume of contaminated stormwater is retained by mulch, soil and plant material. Such bioretention facilities can be designed as separate off-line facilities to assure that the first flush pollutants is not re-suspended and released downstream. Excess runoff greater than the designated first flush is filtered through the bioretention facility and directed into proportional splitters where it is divided into diversion and bypass volumes based on specific predevelopment infiltration and runoff rates. The double weir splits the runoff so that the portion of post development hydrograph created by buildings and impervious surfaces is diverted into distributed infiltration facilities and the pre-existing runoff flows are routed downstream. This method most closely recreates the pre-development hydrograph for the design storm as shown in figure 1.

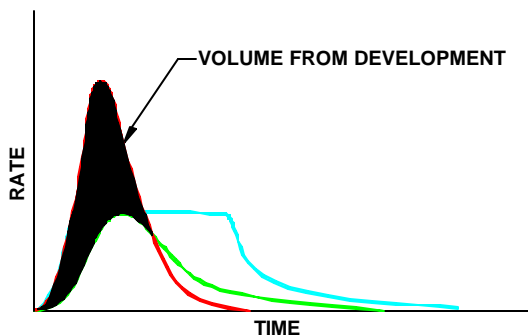


Figure 1 – Runoff volume caused by development above pre-development peak flows.

To infiltrate the total difference in volume for all design storms using a double weir and distributed infiltration facilities, one weir would be designed to emulate the predevelopment runoff while the second weir would be designed to emulate increase in runoff caused by site development. This concept is easily conceptualized as a level curb with two Vee-notch weirs sized for the bypass and diversion flow rates as shown in figure 2.

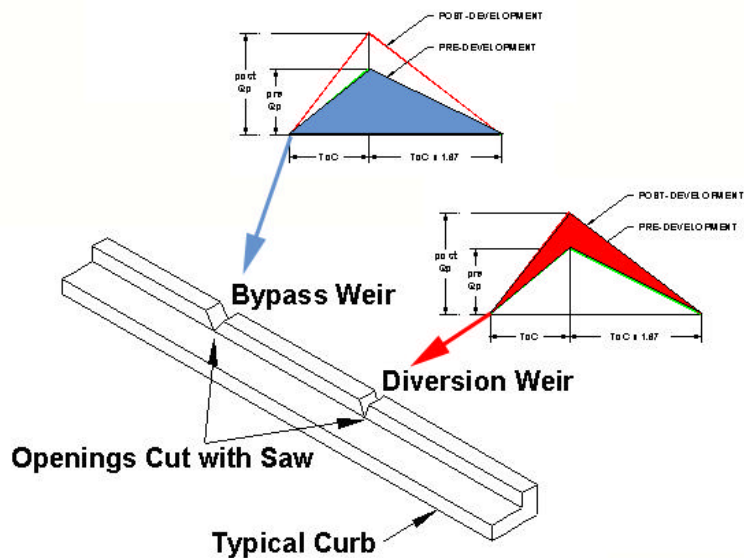


Figure 2 - Level roadside curb with two Vee-notch cuts of different size corresponding to conceptual hydrographs for small and large flows.

As water backs up against the curb, it is split into two volumes proportional to the weir openings as it passes through the curb. The proportional flow splitter apparatus can also be comprised of a drop-inlet or other water conveyance device with two Vee-notch weirs designed in specific proportions to the predevelopment rates of stormwater infiltration and runoff. The diversion volume is directed into distributed infiltration facilities and the bypass volume is cleaned and directed to an existing drainage outlet.

What are the benefits to be gained through the application of distributed split-flow systems?

Stormwater management, as it is often practiced, satisfies the single purpose of storing runoff and releasing it at flow rates that do not exceed the pre-development peak flow rates. This is generally intended as a local flood control practice. The process is most often accomplished by detention structures designed to hold the increase in runoff, and outfall structures designed to release water at specified discharge rates. This practice, however, fails to address issues such as: (1) downstream flooding from combined detained flows; (2) groundwater and stream base flow depletion; (3) decreased wildlife habitat; and (4) non-point source pollution. This current concept of stormwater management by delayed discharge is flawed because the combined effect of different detention facilities often causes downstream flooding while simultaneously depleting groundwater and stream base flow. Stormwater management strategies that include some form of infiltration can satisfy the goals of mitigating effects of impervious surfaces and maintaining pre-development runoff characteristics. As a result, on-site infiltration currently offers the greatest opportunity for solving our urban runoff and non-point source pollution problems.

The most logical and practical system of responsible stormwater management is to sustain the natural flow rate and volume of stormwater runoff by duplicating pre-development runoff hydrographs in post-development conditions. In theory, pre-development runoff conditions can be duplicated after development using existing infiltration based Best Management Practices (BMPs) such as porous pavement, dry wells, infiltration trenches, basins, etc. However, on-site infiltration is not widely accepted in current practice as a viable stormwater management concept because of short-sighted past infiltration practices. Therefore, urban runoff problems continue to be addressed by designing stormwater detention systems. Adaptations of these traditional stormwater management strategies have had limited success in protecting aquatic

environments, because they are simple modifications of techniques intended to control peak flow rates and are not intended to address issues of ecological protection. An alternative stormwater management strategy is needed that will approach stormwater as an environmental resource and be compatible with land development practices.

There are multiple stormwater management benefits to be gained through the application of such an alternative stormwater management strategy including:

1. reducing on-site and downstream flooding
2. reducing flooding caused by combining detained runoff
3. reducing site and regional stormwater systems cost
4. reducing duration of peak storm flows
5. reducing soil erosion, downstream scouring and silting
6. reducing non-point source and thermal pollution
7. replenishing groundwater
8. restoring downstream base flow and wildlife habitats
9. enhancing esthetics and recreational opportunities
10. improving safety by elimination of detention basins

When can distributed split-flow systems be best utilized?

Preliminary studies still under way show that split-flow systems can be designed to fit on sites with an impervious surface coverage of up to 80%. These systems can often be designed to fit within the space used for existing detention basins. This would, however, not meet the goal of distributing recharge throughout a site. The more distributed a system is, the more it costs because of increased piping to convey bypass flow to a discharge point and less efficient use of infiltration facilities compared to clustering them in one location. This highlights a need for design standards to help assure that split-flow systems will be used to preserve a site's natural hydrology and not simply used to create more land for building on each site. Sites using split-flow systems need to incorporate open space immediately down slope from impervious areas. These sites should also be designed with open space distributed throughout the development. Ideally, developments can be designed such that most paved surfaces are built with porous material and the split-flow systems are only needed to control runoff from buildings. The split-flow strategy's decentralized design also creates additional design flexibility, as suitable locations for large stormwater facilities become a low priority. An additional advantage of the split-flow strategy is that once calculations are complete, split-flow systems are simple to design because each impervious area can be designed separately. There is no need to run routing models commonly used to size detention systems as long as the split-flow facilities do not overflow into each other. Providing an overflow drainage system to existing discharge outlets prevents the potential for the facilities to overflow into each other. This ability to design each stormwater facility separately allows simple revisions if development plans are changed or phased. Even years later as residents add more impervious areas such as additions, out buildings, or surfaces, split-flow facilities can be added to maintain the predevelopment hydrology. Simple regulations need to be written that specify the size of split-flow facilities based on square footage of new impervious areas created by landowners. This would even allow easy retrofits to restore a site's natural hydrology years after a development is completed.

What are the hydrological calculations needed to design these systems?

The bypass weir is sized for pre-development peak flow rate and the diversion weir is sized for the difference in pre and post development peak flow rate. Using a chart such as the Vee-notch weir nomograph shown in figure 3, each weir can be sized based on identical head and different flow rates.

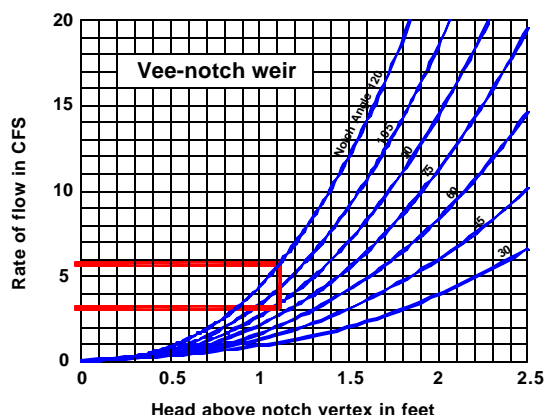


Figure 3 - Vee-notch weir nomograph showing flow rate, hydraulic head, and corresponding Vee-notch weir angles.

For example, if the pre-development peak runoff rate is 5.6cfs and the post-development peak runoff rate is 8.5cfs, the bypass weir would be sized for 5.6cfs and the diversion weir would be sized for 2.9cfs. Using the Vee-notch weir nomograph, the bypass weir angle could be 120 degrees and the diversion weir angle could be 90 degrees as long as the weirs are constructed at the same elevation.

The total volume difference between pre- and post-development design storms can be calculated with the equation:

$$(\text{post } Q_p \times \text{ToC} \times 80.1) - (\text{pre } Q_p \times \text{ToC} \times 80.1)$$

while the total volume for the bypass can be calculated with the equation:

$$\text{pre } Q_p \times \text{ToC} \times 80.1.$$

However, the key to success with a stormwater management system based on this strategy is to install proportional flow splitters for each impervious surface and distribute the flow from the diversion weir into individual infiltration facilities. This requires that the flow splitters be designed to divide the runoff from each of these surfaces into portions that emulate the predevelopment runoff flows and the difference in predevelopment and post development flow for each individual surface which will not be the same as the ratios for the entire drainage area. This is done by sizing each individual pair of Vee-notch weir angles for the proportional flow splitters based on the predevelopment runoff and the increase in runoff caused by each individual impervious surface. The volume of runoff that needs to be infiltrated for each individual impervious surface can be calculated with the equation:

$$\text{Volume} = \text{individual impervious surface area} \times \frac{((\text{post } Q_p \times \text{ToC} \times 80.1) - (\text{pre } Q_p \times \text{ToC} \times 80.1))}{\text{total on-site impervious surface area}}$$

This volume should be based on the largest design storm chosen according to the acceptable level of flood risk for the site design. This allows the stormwater management system for each impervious area to be designed independently based on unique site conditions.

How can these systems be used to meet current stormwater regulations?

Traditional stormwater management regulations require peak flow rates be maintained at predevelopment levels. New regulations also regulate total maximum daily loads for non-point source water pollution. A

few regulations address some level of runoff volume reduction but do not require runoff volumes be maintained at predevelopment levels. Split-flow systems, however, are based on the premise that we can recreate predevelopment runoff rates, volume and quality in urban development and that preserving the existing hydrology is a better way to manage stormwater. This is a change from traditional stormwater management practices designed to accommodate development by disposing of runoff as quickly as feasible. Many stormwater regulations currently place runoff in the category of flood hazard planning based on the view that stormwater is a useless and unwanted byproduct of development that should be collected and removed as quickly as possible. This is accomplished through systems of inlets, pipes, and basins that decrease infiltration, stream baseflow, groundwater recharge, and degrade water quality. However, stormwater can also be viewed as a renewable natural resource that sustains our streams, replenishes our lakes, and recharges our ground water supplies. This renewable public resource is owned by all of us, a result of a natural process, used as an economic resource, and has an enormous impact on the quality of other ecosystems. As a public resource, it's positive and negative economic externalities need to be acknowledged. If sites are properly designed, this resource can be managed to prevent flooding as well as safeguard our lakes, streams and groundwater. If site are not properly designed, this resource will flood downstream properties and destroy aquatic ecosystems. Hence, a basic goal of this alternative stormwater management strategy is to meet our environmental goals and work within our land development needs by: (1) not increasing down stream flow rates, (2) reducing non-point source water pollution, (3) recharging at predevelopment rates, and (4) not polluting our ground water. In theory, if runoff volumes were maintained throughout the site at predevelopment levels, peak flow rates would also remain at predevelopment levels. It could, however, be difficult at this time to convince local stormwater regulators that controlling runoff volume will control peak runoff rates. Further studies using in ground testing will be needed to show how these systems will perform under actual development conditions.

What are the best methods for integrating these systems into site design?

The crucial element for success with the split-flow stormwater management strategy is to install small flow splitters for individual paved surface and distribute the runoff into multiple small-distributed infiltration facilities. This is best done by sizing each proportional flow splitter on the increase in runoff caused by each impervious surface. For example, a building erected on land with a runoff coefficient of 70 would require the weir angles designed for 7 cfs and 4 cfs. This would result in one weir having a 90° Vee-notch angle while the other weir would have a 60° Vee-notch angle. These flow splitters can then be distributed throughout the site in existing open space or landscape islands as shown in figure 4.

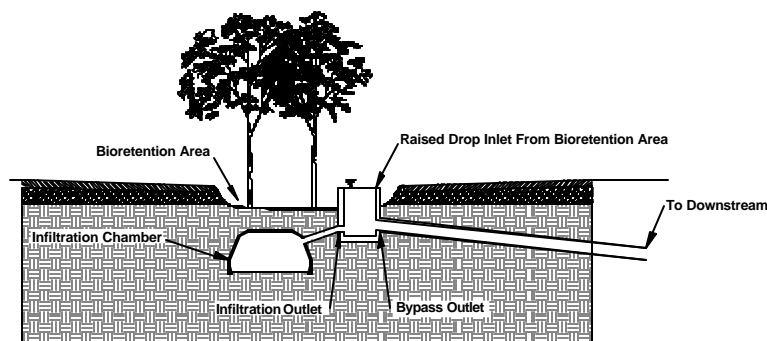


Figure 4 – Example split-flow facility: depressed landscape island in parking lot with bioretention area, raised drop-inlet flow-splitter, underground infiltration chamber for diversion flow and bypass to downstream outlet.

This ratio could be used in all the flow splitters used for impervious surfaces on site to control the peak flow rates for the entire development. Similar ratios can be derived for other runoff coefficients or other runoff methods. An advantage of the split-flow strategy is that the volume to be infiltrated is precisely the same as the excess runoff created by the development and not any larger as in other infiltration and bioretention methods. This is especially important on sites with clay soils where very little water recharges naturally. The proportional flow splitter would assure that the same volume and no more would need to be infiltrated into the ground after development in order to control the peak flow rates. A second advantage of this strategy is that the volume to be infiltrated is adjusted by the flow splitters for each storm and not based on a specific design storm. However, without adequate distribution on site the system will not work because there must be sufficient soil area for the diversion volume to be able to infiltrate in a reasonable time. Therefore, many small split-flow facilities need to be placed throughout a site as shown in figure 5.

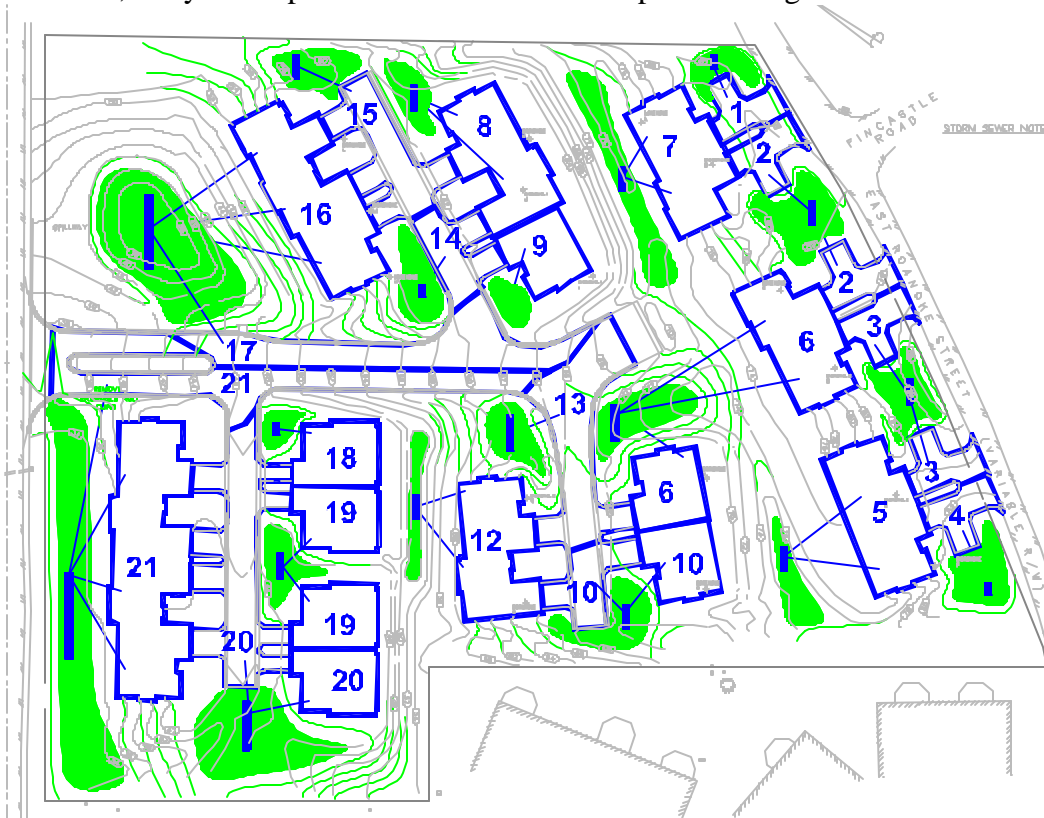


Figure 5 – Example plan with location of Split-Flow facilities. Impervious surfaces are outlined in blue. The underground infiltration chambers are shown as small blue rectangles while above ground bioretention facilities are shown in green. Thin blue lines show which impervious areas and buildings are directed to which split-flow facilities.

This concept will succeed in controlling peak flow rates where other infiltration and bioretention strategies have not because the amount of stormwater to be infiltrated in each facility is carefully controlled and it is never concentrated in large quantities. The stormwater management system will still control the peak flow rates by distributing and infiltrating the difference in volume over the entire site.

How can these systems help guide evolving stormwater policy?

Many communities have implemented stormwater utilities to pay for building storm sewers and runoff treatment facilities. Some communities base their fees on impervious surface areas for each property.

Many of these communities also allow reasonable reduction in fees based on reduction in volume, which will hopefully encourage more environmentally responsible stormwater management practices. If a builder installs a system to control the runoff rate and volume and can demonstrate there is no change in the existing hydrology, the fee could be waived. This can provide an incentive for developers to install environmentally responsible stormwater management systems if the costs are reasonable. A preliminary study shows that split-flow systems would likely cost the same or less to build than detention systems. Split-flow systems would provide non-point source pollution and flood control benefits to the community, as well as lower the owner's annual operation cost by eliminating the annual stormwater utility fees. As a result, the split-flow strategy can provide a reasonable financial alternative to existing detention practices, which could become a financial incentive for developers to install more environmentally responsible stormwater management systems. Maintenance costs should be the same as existing bioretention systems, however, further research is needed.

The split-flow strategy intends to preserve the predevelopment site hydrology by duplicating year-round natural infiltration volumes. Water balance studies indicate that spring flooding results when the ground is saturated from winter precipitation stored in the soil and the soil's water absorption capacity is greatly reduced causing increased runoff. The split-flow strategy would emulate these conditions and therefore likely infiltrate less precipitation during the spring flooding season. Detention systems, on the other hand, are not designed for, or affected by, soil infiltration capacity, which changes during the year. In effect, split-flow systems could reintroduce local stream flooding that may have been prevented with detention. As a result, a question arises regarding the conflict between the wisdom of restoring natural processes, which could include local spring flooding, versus installing detention systems that could artificially control local spring flooding but destroy aquatic ecosystems. Conversely, development has also been shown to cause increased year-round flooding and multiple detention systems can combine and elevate these floods depending on how the basins' outflows combine downstream. As stated, the split-flow strategy is based on the premise that preserving the natural hydrology is a better way to manage stormwater. However, the land development industry has historically operated under the strategy that we should modify natural systems to accommodate development rather than modify development practices to accommodate natural systems. Changing these basic beliefs and operation procedures will likely require numerous long-term demonstration studies.

Conclusion

The goal of this paper is not to claim excellence of one stormwater management method over another but rather to contribute an additional management option that hopefully can start to change our stormwater management expectations. The intent is to demonstrate that a viable stormwater management strategy can be derived from the premise that preserving the natural hydrology is a better way to manage stormwater and that modifying land development practices to accommodate natural systems can be more effective than modifying natural systems to accommodate land development practices.

The split-flow strategy, however, is still a theory that needs in-ground testing to discover what problems will result in the design and construction processes. For example, including construction erosion and sediment control measures on sites with split-flow systems will create additional design challenges. Current design and construction practices incorporate temporary sediment basins in the location of future detention facilities. These temporary sediment basins are then converted to detention basins when construction is completed. However, split-flow systems do not need detention basins. Therefore, other erosion and sediment control solutions will be needed during construction. Possible solutions include: use alternative prevention and control methods that do not require sediment basins, build temporary sediment basins that can be converted

into bioretention facilities when construction is completed, or build temporary sediment basins elsewhere on site that can be removed after construction is completed. Regardless of what methods are used for erosion and sediment control, the split-flow systems should not be activated until the site is completely stabilized. Additional research will be needed as other site design and construction implications arise.

Preliminary research shows that split-flow systems can be comparable in construction cost to detention systems depending on the complexity of the stormwater designs. Findings show that split-flow infiltration practices can often be used to lower the cost of on-site stormwater management and provide a higher level of environmental protection. Findings also indicate that non-point source water pollution reduction objectives currently achieved by other infiltration and bioretention strategies could be more cost effective construction using the split-flow strategy. Notable implications that need to be addressed with further development of the split-flow strategy include: stormwater policy, site design and construction practices, runoff modeling and environmental concerns.

Coffman, L. (2000). Low-impact development manual. Prince Georges County, Maryland Department of Environmental Resources.

Echols, S.P. 2002. Split-flow method: Introduction of a new stormwater strategy. *Stormwater -The Journal for Surface Water Quality Professionals*, 3(5): 16-32.